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RECENT LCA DEVELOPMENTS IN WASTE MANAGEMENT

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SUMMARY: Based on 10 years of experience we briefly present key issues which should receive special attention when waste LCA is performed. Attention is paid to the importance of good data on waste composition, the contribution of environmental impacts from capital goods, assessing the value of recovered materials, nutrients and energy, the representativity of external life cycle inventory data bases, how we address uncertainty and important factors in defining future scenarios.

1. INTRODUCTION

Life-Cycle-Assessment (LCA) has gained importance worldwide as a tool for assessing the environmental aspects of integrated waste management systems. Recent reviews (Laurent et al., 2014a+b) counted 222 scientific journal papers published on the issues with a majority of the papers appearing during the last 5 years. LCA was developed more than 20 years ago for assessing industrial products in a life-time-perspective, but has been used systematically in the assessment of waste management only during the last 10 years. LCA has gained focus within waste management because waste management has become very complex the recent years and the use of the simple Waste Hierarchy has shown its limitations. The main factors are:

- Recovery of materials, nutrients and energy has gained more focus and demands a range of technologies to manage the waste
- Introduction of source separation leads to several separate streams of waste materials to be handled in the waste management systems
- Source separated materials must usually be upgraded prior to recycling resulting in reject streams that need other treatment
- Several technology options are available for handling the organic waste as well as for recovering fuels and energy

Only a thorough system analysis and careful assessment of the value of the recovered materials, nutrients and energy can quantify the environmental benefits of a complex waste management system and contribute to environmentally sound decision making regarding waste management.

This paper briefly outlines some key issues in applying LCA to waste management systems based on experiences from the last ten years obtained by DTU Environment. We estimate that DTU Environment has been part of 35% (80) of the more than 220 papers published on LCA in

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waste management during the recent years; the majority of the work performed by DTU Environment used the waste LCA model EASETECH/EASEWASTE (Clavreul et al. 2014).

2. KEY ISSUES IN WASTE LCA

Performing LCA modelling of any waste management system should follow the standard that is available for LCA modeling in general (ISO, 2006) and should adhere to the European guideline on waste-LCA modelling (European Commission, 2010 & 2011). The standard and the guideline provide a consistent framework for building and documenting a transparent LCA modeling of a given system: producing results that match the problem addressed and eventually the decisions to be made. This paper presents further issues that need specific attention in waste LCA modeling based on recent year's work with LCA modelling around the World for a range of waste types and waste issues.

According to a recent review (Laurent et al, 2014a), SIMAPRO was the most frequently used LCA model for waste management systems followed by the model EASEWASTE/EASETECH. SIMAPRO is well-suited for the purpose, if a single material (paper, glass, polyethylene, etc.) is in focus and complex waste management technologies as landfilling and use-on-land are not important. However, for a waste management system with sorting at source and complex waste streams and a range of technologies which split the material flow we are convinced that a specific waste-LCA model is needed. If use of treated organic waste on land is in question or landfilling constitutes a significant part of the waste management system a specific waste-LCA models is needed as well. EASETECH is currently the only advanced model available free of charge for research use.

2.1 Good waste data

Datasets on waste composition at the source of the waste generation representing material fractions as well as the chemical composition of each material fraction are few (Riber et al., 2009). However, such data is needed if the waste management system includes source sorting of different fractions for separate collection or includes mechanical sorting of waste. The detailled data is a prerequisite for keeping track of materials, falsely place materials as well as the chemical composition. We do not expect that municipal waste is identical around World (see e.g. Eisted & Christensen (2011) regarding Greenland , Starostina et al. (2014) regarding Siberia, Edjabou et al. (2015) regarding Denmark), and we may need to be aware of differences between countries and regions within a country before we "borrow" data. It is recommended to use local data to reduce the uncertainty. Key parameters are the content of paper, plastic, organic waste and the water content. But also "foreign" fractions, e.g. batteries (Bigum et al., 2013), although found in small quantities can strongly affect the chemical composition in terms of trace metals. It may also be important to address what the informal sector of scavengers etc. removes from the public waste stream since this can significantly affect the composition of the waste collected.

2.2 Role of capital goods

Capital goods are in this context what is used in the waste management as facilities and equipment (invested materials and energy) to make the system work: Bins, trucks, treatment plants, machinery, buildings, landfill installations, etc.. Brogaard and Christensen (2012) and Brogaard et al. (2013a+b; 2015) developed detailed inventories of materials and energy used in providing the infrastructure for waste collection, incineration, biological treatment facilities (composting, anaerobic digestion) and for landfilling. This infrastructure also carries an environmental impact and Brogaard and Christensen (2015) showed that the capital goods should not be excluded from the waste LCA, although capital goods in terms of Global Warming may not always be important. Key aspects are the use of steel in the infrastructure and how well it is possible to recover and recycle the materials at the end of life when the trucks are scrapped and the facilities and equipment are demolished.

2.3 Assessing the value of recovered materials

Recycling of waste is in focus in many countries and several countries are establishing target values for recycling of a range of materials. The waste management sector can prepare the recyclables to a varying degree depending on facilities, transport and economic issues, but in all cases the materials need upgrading before it can be used as feedstock in an industrial process. The upgrading typically involves removing of faulty placed items and sorting in qualities. The later could be glass sorted into colors. In an LCA perspective it is really not important where in the system this upgrading takes place because the LCA uses a life-cycle-perspective. The important issue is, however, that there modelling-wise is a correct match between on the one hand the amount and quality of recyclables delivered from the waste management sector and on the other hand the recycling process that the receiving industry uses and the quality of products that they produce. The collection and upgrading of the recyclables as well as the actual industrial recycling process all are loads to the environment through their use of materials, energy and emissions, while the savings are obtained from the products society does not need to produce by another virgin-based industrial processes. It is very important that when various databases are used to obtain quantitative assessments of these aspects that the material quality issues are consistent throughout the value chain. Otherwise we can easily overestimate the benefits from recycling.

2.4 Assessing the value of recovered nutrients

Bringing treated organic waste back to land, in LCA models often referred to as Use-On-Land, is a part of many waste management systems. The benefits are the recycling of nutrients and in some case also the addition of stable carbon to the soil. However, in compost and digested organic matter, the nutrients are present in different chemical forms than in mineral fertilizers, which often are assumed to be the fertilizer saved when organic waste is used on land. The retention time of P in the top soil is so long than for all practical purposes a 1-to-1 substitution can be assumed (amount of P in compost saves production of the same amount of P in mineral fertilizer), but for N the differences in chemical forms and hence in availability for plant up-take and for leaching are significant and should be accounted for. The actual quantification of theses aspects are highly dependent of national regulation of fertilizer use and requires advanced eco-agricultural models since the environmental consequences may last for decades and even centuries. Yoshida et al (2015) provides the newest insight into the complexity of how to quantify the environmental impacts of using organic waste on land. The main point is that for N the substitution is not 1-to-1 in fertilizer application and the organic fertilizers have often higher environmental impacts that the mineral fertilizers because mineralization is continuing after the crops have been harvested leading to increased leaching.

2.5 Assessing thermal energy reovery

Energy recovery from waste is an essential part of modern waste management. In many countries, waste management has changed from primarily focusing on treatment and final disposal of residual streams from society to a sector that contributes significantly to energy provision. In addition, waste is gaining increasing interest as an option for reducing dependence on imported fossil fuels. In addition to anaerobic digestion, the main thermal technologies are: (i) mass-burn waste incineration, (ii) co-combustion with other fuels, (iii) thermal gasification and pyrolysis. Generally, mass-burn waste incineration is the most robust technology for energy recovery, because this technology accepts a wide range of waste materials (size, sources, composition). Co-combustion, gasification, and pyrolysis are generally less widespread and mainly applied on pre-treated waste or sub-streams of urban waste (e.g. Solid Recovered Fuels, SRF, or Refuse Derived Fuels, RDF). While inventory data for incineration of mixed municipal solid waste are available from various databases, it is very important that the emissions from the incineration represent the specific waste in question (Astrup et al., 2011). Here there is an important difference between generic LCA models and waste LCA models (Gentil et al., 2010); in the latter the emissions are reflecting the actual composition of the waste fed to the incinerator. Similar issues are related to the energy recovery, which should be determined based on the energy content of the actual input waste. A recent review study (Astrup et al., 2015) evaluating 250 individual case-studies (136 journal articles) focusing on energy recovery, demonstrated that very few LCA studies carry out consistent modeling of waste-to-energy technologies, in many cases without stating key information describing the modelling. As recovered energy and the associated substitution of energy in the energy system in many cases is decisive for the outcome of waste LCAs, transparent modelling and description of assumptions are essential.

2.6 The representativity of external life cycle inventory data bases

Inventory data used for LCAs vary in transparency and the quality of background information. Therefore, it is difficult for the LCA practitioner to choose the right datasets. Some datasets appear to be equal according to the name and short description, but the data are different. Large variations in emissions of CO_2 were shown for selected materials in Brogaard et al. (2014) who collected and compared 270 datasets for the primary production and 96 datasets for the secondary production of 14 materials (office paper, newsprint, cardboard and corrugated cardboard, plastics (HDPE, LDPE, LLDPE, PET, PP, PS and PVC), steel, glass and aluminum). The mean and standard deviations of the collected data for CO_2 emission showed that primary production produces higher emissions than secondary production, thus suggesting in a direct comparison that it is beneficial to recycle. Conversely, the study also showed the highest and lowest values, which suggest that it is possible to combine datasets in a way that the recycling of materials does not appear beneficial. Choosing the right dataset for an LCA is therefore very important, since this choice can dramatically affect the results. The ISO standards (ISO, 2006) describe how to prepare inventory data and how to describe background information in a transparent way, but the standard is seldom seen followed and branch organisations should be encouraged to publish more industry data.

2.7 Assessing resources

Consumption of resources has received increasing attention in society within recent years and the importance of the recovered resources has gained more and more political attention with respect to waste management. Within LCA, resources can be assessed by one of several resource depletion indicators (Rørbech et al., 2014). While including these indicators in waste LCA modelling is not different from other impact categories, interpretation of the indicators often require specific attention. A wide range of resource depletion indicators exist applying a range of different assessment principles, which subsequently affects the resulting impact scores of the modelling (Rørbech et al., 2014): some indicators include more resources than others, and some indicators place higher importance on energy resources (e.g. fossil resources and/or biomass) while others on metal resources. Selection between these resource indicators can be debated; however, it is recommended that interpretation of the results reflects the underlying assessment principles in order to reach meaningful conclusions (Rørbech et al., 2014). This area definitely needs more work in the future.

2.8 Addressing uncertainty

Results are subject to combined effects of parameter, scenario, and model uncertainties (Clavreul et al., 2012), and uncertainty analysis is essential for a balanced interpretation and use of waste LCAs in decision making. Scenario and model uncertainties are usually addressed with varying framework (e.g. energy system) and modelling choices (e.g. geographical and temporal scope, impact assessment methods, etc.). Regarding parameters, common key variables in waste LCAs are usually related to the waste composition, recovery efficiencies for materials and energy, consumption of fuel and distances, etc. These aspects are commonly selected *a priori*, but should rather be systematically identified on a case-by-case basis, especially in view of increasingly wide and complex state-of-the-art waste LCAs.

Clavreul et al. (2012) recommend using a tiered approach that consistently addresses parametrical uncertainties. A contribution analysis and a sensitivity analysis should be carried out before selecting parameters for uncertainty and discernibility analyses. Herein, practitioners should carefully choose and justify the choice of uncertainty representation, e.g. by means of probability of possibility theories (Clavreul et al., 2013). For the specific case of waste LCAs, EASETECH has been designed in order to facilitate uncertainty propagation by means of a Monte Carlo sampling method (Clavreul et al., 2014), similar to most other LCA models (Lloyd and Ries, 2007). Sensitivity and uncertainty analysis are thus run independently, and uncertainty is usually propagated only for the most sensitive parameters.

The full influence of input parameters can be obtained coupling the concepts of sensitivity and uncertainty in a Global Sensitivity Analysis (GSA) perspective (Bisinella et al., 2015). The method proposed in Bisinella et al. (2015) allows a systematic identification of key parameters and a thorough understanding of their influence on the model uncertainty, which can be sparsely represented.

2.9 Important factors in defining future scenarios

Waste LCAs are increasingly addressing long term management choices and practitioners are asked to quantitatively compare environmental impacts that extend from the present day framework conditions. In absence of regulations on how to address future scenarios in waste LCAs, potential developments of the framework conditions have become the drivers for technology selection, especially when modern waste technologies have reached a level of environmental performance that often does not allow LCAs to identify better management alternatives.

However, future scenarios based on present-day understanding of the modelled system can be potentially misleading. Key aspects influencing the results should be systematically addressed in scenarios of future waste management systems, in order to ensure understanding governing mechanisms. In this context, a GSA approach (Bisinella et al., 2015) offers a fast and valuable approximation for the quantification of importance of input parameters, both for present day and future systems.

3. CONCLUSIONS

LCA modelling of waste management systems has made significant progress in recent years and is becoming an integrated part of waste management all around the world. LCA modeling provides an unprecedented overview of what matters in a waste management system seen from an environmental point of view. This is a knowledge that is a prerequisite for a balanced decision making regarding new systems, new technologies and operational focus. However, waste LCA is somewhat different from traditional LCA of industrial products or services and several issues need special attention in order to produce a balanced and transparent LCA. These issues have been briefly mentioned in this paper.

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